Introduction: Jones fractures of the 5th metatarsal are transverse fractures at the proximal metaphyseal/diaphyseal junction that involve the 4/5 intermetatarsal articulation. These fractures are often undisplaced and can be managed non-operatively, but non-operative management is associated with an increased risk of delayed and non-union. Currently, intramedullary screw fixation is considered the operative treatment of choice, but the optimal screw type for this procedure has yet to be defined. Commonly used screws have diameters of 4.5mm to 6.5mm, and it has been observed that fixation failure is more likely to occur when smaller diameter screws are used. To test the hypothesis that fracture repair integrity is related to screw diameter, we performed a biomechanical study analyzing the bending stiffness of Jones fractures repaired with 5.0mm and 6.5mm screws as well as pull-out strengths of the respective screws.

Methods: Twenty-three matched pairs of fresh frozen fifth metatarsals were retrieved from cadavers. There were 15 males and 8 females, with an average age of 74.6 (+/-15) years. The bones were denuded of soft tissue and incomplete transverse fractures at the metaphyseal-diaphyseal junction, extending into the 4/5 intermetatarsal articulation, were created using a sagittal saw. The right metatarsal fractures were fixed using 6.5mm short-threaded stainless steel screws (Synthes(USA), Monument, CO). The left metatarsals were fixed with 5.0mm short-threaded cannulated titanium screws (ACE Surgical Supply, Brockton, MA). Screw length was selected by superimposing the screw over the metatarsal such that the threads were distal to the fracture site and located in the proximal diaphysis. The screw was inserted and the fracture completed before tightening the screw to achieve visible compression at the fracture site (Figure 1).

Canal dimensions: The diameters of the medullary canals of all 46 metatarsals were measured radiographically at the proximal diaphysis.

Lateral cantilever bending stiffness: Twelve pairs of metatarsals were used for stiffness testing. The proximal fragment of each metatarsal was embedded in an aluminum pot using PMMA cement. Prior to embedding, the exposed screw head was covered with modeling clay to prevent contact with the surrounding cement. A 2mm screw was inserted into the lateral cortex of the metatarsal head to provide a discrete contact point for subsequent load application. The metatarsal was then rigidly mounted in a horizontal orientation in an Instron model 1321 servohydraulic testing machine and displacement was applied to the distal contact point at a rate of 0.1 mm/second in a lateral-to-medial direction until failure was observed. The bending direction was chosen because non-unions typically display gapping laterally. Stiffness was calculated from the slope of the load-displacement curve.

Pull-out strength: Pull-out testing was performed on 11 matched pairs of metatarsals to confirm the subjective impression of poor thread purchase with the 5.0mm screws when compared with the 6.5mm screws. The distal end of the bone was embedded in a cylindrical aluminum pot using PMMA cement such that the fixation screw and pot were coaxial. The metatarsal tuberosity was removed to expose the head and shank of the fixation screw. The specimen was attached to the table of an Instron model 1321 testing machine, the head of the fixation screw was grasped, and the screw was extracted from the metatarsal at rate of 0.1 mm/second. The maximum tensile load developed during screw pull-out was recorded.

Statistics: Paired Student’s t-tests were used to compare stiffness, pull-out strength, and canal diameter between right and left metatarsals. Mixed effect ANOVA was performed to analyze the effects of donor age and canal diameter on stiffness and pull-out strength.

Results:

Fracture stiffness: Because the lever arm varied between specimen pairs, stiffness results were normalized to a standard lever arm for comparison. There was no significant difference (p>0.05) in bending stiffness between fractures fixed with 6.5mm screws and 5.0mm screws (n=12 pairs). Neither donor age nor intramedullary diameter showed a significant effect (p>0.05) on bending stiffness for either screw size. Different mechanisms of failure were noted to occur depending on screw type. When the right metatarsals (6.5mm screw) were subjected to bending, the fracture opened laterally due to collapse and crushing of the medial metaphyseal bone in the proximal fragment, while the shaft of left (5.0mm screw) metatarsals translated distally along the screw because of poor thread purchase, enabling the fracture to open.

Pull-out strength: The pull-out strength of the 6.5mm screws (1037.4+/−349.9N) was significantly greater than that of the 5.0mm screws (416.8+/−349.9N) (p<0.05). Screw diameter had a significant (p<0.05) effect on pull-out strength, while the effect of canal diameter was not significant (p>0.05). The 5.0mm screws had greater pull-out strengths in 2 of the 11 pairs.

Discussion: Because Jones fracture non-unions exhibit gapping on the lateral cortex clinically, we performed cantilever bending in a lateral-to-medial direction to simulate the loading mechanism that appears to be responsible for fragment motion and non-unions in vivo. The failure mechanisms observed during cantilever bending indicated that the threads of the 5.0mm screws often lost their purchase, allowing the bone fragments to separate, and the pull-out testing results support the finding of sub-optimal thread purchase with the smaller diameter screws.

Based on the results of this study, we believe that 4.5mm and 5.0mm screws may be too small to achieve optimal fracture stabilization if the medullary canal is large or the cancellous bone is of poor quality. A larger diameter screw provides greater resistance to pulling out of the distal fragment. We have shown that most metatarsals can safely accommodate a 6.5mm screw. Despite the biomechanical advantages of the 6.5mm screws, their usage is not recommended for metatarsal canal diameters of less than 5mm because of the demonstrated fracture risk.

Figure 1. Radiograph of metatarsal fractures fixed with a 6.5mm screw (left) and 5.0mm screw (right).